

Radiation Workers' Handbook

Radiation Control in the Mining & Mineral Processing Industry

Uranium

Mineral Sands

Rare Earths

NORM



Radiation Workers' Handbook

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Image Credits

PLEASE NOTE: This booklet has been written about the hazard of radiation and its controls. Other hazards have not been discussed in detail. Safety manuals are available at mines and mills which deal specifically with other hazards. Radiation has been given a booklet of its own, not because it is the greater hazard, but because it is invisible and not widely understood.

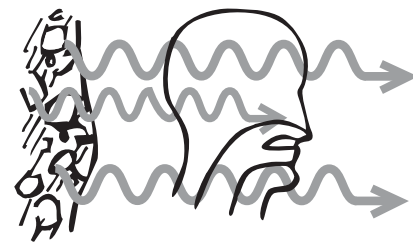
Quick-Start Summary:

Radiation Dose Delivery Pathways, their monitoring and control

As a worker in the mining and resources industries who mines or processes radioactive materials, or treats radioactive wastes, you can be exposed to radiation. This radiation dose must be kept 'As Low As Reasonably Achievable', and below the legal limit for radiation workers. On average, radiation workers get annual doses between a tenth and a quarter of the allowable limit. However the radiation exposures you receive in your workplace do need to be controlled and monitored.

You can get a radiation dose at work via four 'dose delivery pathways'.

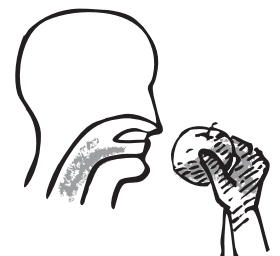
- **gamma 'shine'** (irradiation) e.g. from outcrops or stockpiles of ore;
- **inhalation of radioactive alpha emitting dusts or fumes;**
- **ingestion** of radionuclides in dust, food or water; and
- **inhalation of radon decay progeny** (or 'radon daughters') in mine air.



All these pathways contribute differently depending on local conditions.

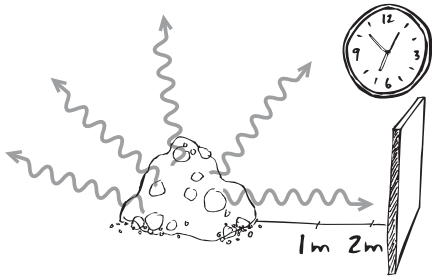
General Principles of Dose Control

Radiation Type (Dose Pathway)	Controls	Monitoring
Gamma	Time, Distance, Shielding	Personal Radiation badges, survey meters
Alpha emitters in airborne dust	Dust suppression, extraction systems, Personal Protective Equipment (PPE)	Personal Air Samplers
Radon Decay Products	Ventilation, PPE	Workplace air sampling
Ingestion of Dust	Personal & cribroom cleanliness	Surface alpha contamination surveys



For protection against gamma rays ('gamma shine'):

TIME, DISTANCE, and SHIELDING are used to control gamma dose. Minimise your time exposed to the source, or increase your distance from the source or use shielding (sand, lead, steel, concrete or soil).



These controls will usually only be needed if you are working for many hours next to large masses of high grade ore or waste. These controls could be needed if you are working with >5% uranium ore; 'bulker' bags of monazite, or seafreight containers of drummed radium scale.

For protection against airborne dust containing uranium, thorium or radium:

GOOD DUST CONTROL IS IMPORTANT, whether the material is ore, product or tailings.

This is important in exploration drilling and blasthole drilling, ore handling, crushing, pulverizing and screening. In *mineral sand plants* the dry processes (air tables, crossbelt magnets, electrostatic separators) all suspend fine dust particles in the air and should therefore be enclosed.

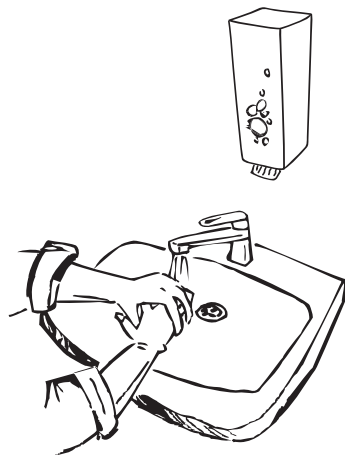
Smelters and sinterplants handling radioactive feeds can produce radioactive fume containing polonium-210 and lead-210, which must be monitored and controlled.

Stay out of any dust cloud if possible. If you cannot avoid airborne radioactive dust or fume, then use a DUST MASK or RESPIRATOR.

For heavy equipment operators, airconditioned cabins supplied with filtered air provide protection against excessive dust.

For protection against dose from ingestion of surface contamination:

SIMPLE WASHING IS EFFECTIVE. Washing your hands properly will remove all dirt and mud, whether it is carrying radioactive substances or not. Wash your hands and face before smoko and meals and ensure cribroom tables are clean.



Packing yellowcake
Beverley



For protection against dose from inhalation of radon decay products:

GOOD VENTILATION IS VITAL. In **underground** uranium mines, good mine ventilation and continuous monitoring are needed to control radon progeny. Most above ground situations (like an open pit mine) will not need active controls, as radon progeny levels will be close to natural background levels.

Other enclosed spaces such as fine ore bins, or enclosed storage sheds containing large amounts of ore or concentrate, or bagged monazite, could produce a buildup of radon progeny. However, radon progeny are very easy to measure, and such spaces should always be ventilated before entry.

Radiation Dose Limits and Comparisons

Worldwide Natural Background Radiation from rocks and soil, cosmic rays, radon in air, and radioactive elements in food, averages 2 or 3 milliSieverts (mSv) worldwide.

Medical radiation doses in developed countries are rising, and now average close to 1 mSv per year.

The maximum permissible annual radiation dose to workers, from their work activities, is 20 mSv.

Most full-time radiation workers (e.g., uranium miners, mineral sand dry plant operators, industrial radiographers, nuclear medicine technicians, medical radiographers and radiologists, radiation laboratory workers) get an annual dose from their work of 2 or 3 mSv, up to a maximum of about 5 or 6 mSv. That is a tenth to a quarter of the Annual Worker limit of 20 mSv.

The maximum permissible annual dose to Members of the Public, is 1 mSv, excluding natural background and medical doses.

The mining-origin doses to people living in Jabiru near Ranger uranium mine, and in Roxby Downs near Olympic Dam, are about 0.01 mSv or 0.02 mSv, a tiny fraction of the limit. Doses to people living near mineral sand mining operations and uranium exploration sites are smaller still.

Mining and processing of uranium, mineral sands, rare earths, and of other radioactive ores, as carried out in Australia, is very well monitored and well supervised. Radiation protection is effective and in many respects leads the way in the development of safety culture in these operations.



Passive air sampling
Beverley

Radiation Workers' Handbook – Radiation Control in the Mining Industry

This Handbook describes how we monitor and manage radiation in the mining and processing of radioactive ores, including uranium, mineral sands and rare earths.

In it we identify Australia's Radiation Protection Codes and Regulations (which must be followed by both the Company and by its workers) and outline the basic principles you need to follow to ensure that; the radiation dose you receive at work will be kept well below the annual limit for workers, prevent the spread of radioactive contamination both on and off site, and ensure environmental impacts are minimized.

***This book is intended for use as a background text
for Radiation Safety Inductions given to all new workers,
but does not take the place of your site specific Radiation Manual.***

*As a worker in an operation handling radioactive materials,
you need to know the basic facts about radiation,
how it is measured and controlled in the workplace,
and what you have to do to work safely with it.*

1 Introduction – Radioactive Ores, their Uses, and Control

Concerns with greenhouse gas emissions from coal and security-of-supply issues with the use of gas and oil, together with the rising demand for electricity worldwide, are prompting many countries to increase their reliance on nuclear power.

There is also increasing use of other metals including zirconium, titanium, tantalum and rare earths, in various high-tech applications, whose ores happen to contain radioactive elements.

As a result, we see many exploration projects drilling for uranium, mineral sands and rare earths, and increasing numbers of industrial operations which mine, process or handle radioactive ores, concentrates, or wastes. All these projects must be managed so that doses to workers and members of the public are kept under control and well below the legal limits.

Australian radiation regulations and legal limits are based on the advice of the International Commission on Radiological Protection (ICRP), which relies on many decades of radiobiology and epidemiology studies.

ERA Rio Tinto Ranger Mine,
Heathgate Beverley ISL Mine,
BHP Billiton Olympic Dam Mine





Nuclear Power Plant
creative commons attribution licence
frutos de blanco

Uranium:

Uranium is mainly used to make electric power. As of 2009, there are about 440 nuclear power plants worldwide, producing about 15% of the world electricity supply, and using about 60,000 tonnes of uranium oxide (U_3O_8) per year. There are plans to build many more nuclear power plants over the coming decades, to meet increasing demand for electricity while reducing reliance on coal-fired power.

Up until the 1970s the main use of uranium was for weapons. In Australia, this included the output of Radium Hill, Rum Jungle, and the South Alligator Valley uranium mines.

After the end of the Cold War, all the nuclear-armed countries were left with far more weapons material than they would ever need. Since the early 1990s, much of the US and Russian weapons material has been blended down with unenriched uranium and recycled as nuclear power plant fuel through the 'Megatons to Megawatts' program. However this fuel source is limited, and by 2015 there will be a shortfall in supply, which new uranium explorers and miners are hoping to fill.

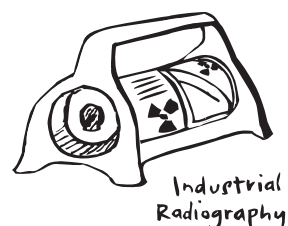
***Australian uranium is only used for peaceful uses.
Its export is closely controlled by the Australian Safeguards
and Non-Proliferation Office (ASNO).***

Uranium is also used in nuclear reactors to make radioisotopes for industry, research and medicine, including diagnostic tests and cancer therapy.

Some Radioisotopes and their Uses:

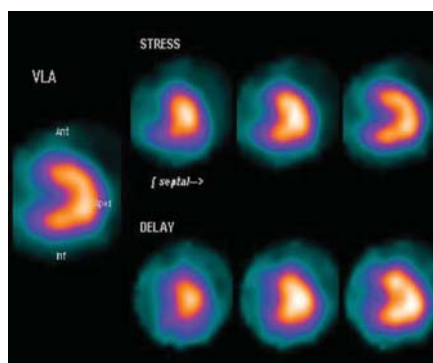
Americium 241	soil moisture / density gauges, smoke detectors
Caesium 137	industrial gauges (slurry density, bin level)
Cobalt 60	radiation sterilization (medical consumables, food etc)
Iridium 192	industrial radiography, radiotherapy
Manganese 54	environmental and industrial tracer studies
Phosphorus 32	biological research
Strontium 90	thickness gauges (paper & plastic sheet production)
Technetium 99m	nuclear medicine diagnostic tests (organ scans)

Americium 241
Smoke detector



Industrial
Radiography

Technetium Heart Stress Test



Mineral Sands:

Other mining operations which handle radioactive material are the Heavy Minerals mining and separation plant operations. These produce zircon, (used for ceramics), and ilmenite and rutile (which are sources of titanium, a high strength temperature and corrosion resistant metal). Heavy mineral sands are radioactive due to the presence of the radioactive element thorium. Thorium is present in monazite, a source of rare earth metals, and also in zircon, and the minor heavy minerals, xenotime and leucoxene.

Rare Earth Elements:

Rare Earths (lanthanum, neodymium, praseodymium, samarium, gadolinium, europium and others) are used in lasers, semiconductors, high strength magnets and other hi-tech applications. Rare earth ores also contain radioactive thorium, so active radiation control is needed in these mines and extraction plants.

Naturally Occurring Radioactive Materials (NORM):

Other types of mines, concentrators, or smelters where you sometimes find radioactive materials are those handling tin, tantalum and niobium, gold, tungsten or molybdenum.

Two radioactive decay products of uranium, polonium-210 and lead-210, have also been found to collect in recycled off-gas dust in iron ore sinter plants and copper smelters. This is due to presence of uranium in the ore as a minor contaminant.

The oil industry, coal washeries, and fertilizer plants also produce radioactive materials, in the form of radium bearing scale inside pipework and vessels, which need to be controlled during maintenance or cleanout tasks.

There are many parallels between the types of radiation found in these workplaces, and how it is measured and controlled.

All use the same monitoring methods and standards.



NORM contaminated pipes from a coal washery





Anna Roentgen's hand

2 History

Wilhelm Roentgen discovered x-rays in 1895. Within a few months x-rays were being used by doctors worldwide. A year later the first reports of x-ray skin burns received by x-ray technicians were published in the medical journals, and then reports of vomiting and diarrhoea, and blood cell loss (what we now call Acute Radiation Syndrome).

The ability of large doses of x-rays to cause injury and illness were discovered very quickly.

Henri Becquerel discovered 'x-ray-like' rays from uranium in March 1896, the first discovery of natural radioactivity.

Marie Curie picked up on Becquerel's discovery and successfully separated radium in mid 1898. Pierre Curie, her husband, discovered that it caused a burn that took months to heal after sticking a speck of radium on his arm.

By 1905, radium's ability to kill rapidly dividing cells was being used for cancer therapy. This demand grew so quickly that by 1911 radium was valued at \$200,000 per gram.

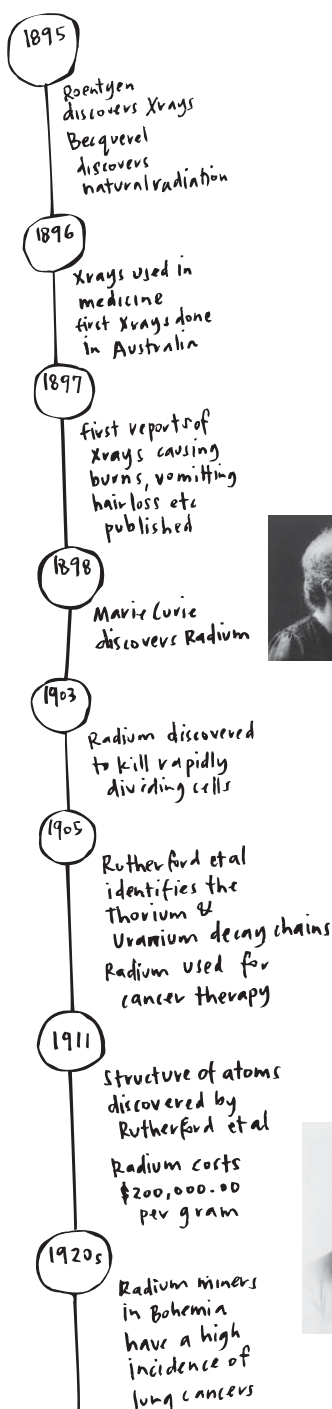
The ability of large doses of external radiation (from both x-rays and radium) to both cause and cure cancer were discovered very early.

From 1899 to 1911, Ernest Rutherford and his co-workers were the leaders in studying natural radioactivity. They discovered:

- there are 3 types of radiation from minerals, which they named alpha, beta, and gamma rays, with different penetrating powers;
- alpha rays are high speed ionized helium atoms, beta rays are high speed electrons, and gamma rays are like x-rays;
- uranium and thorium are parents of a series of radioactive 'decay chain daughters';
- each radioactive element has its own set decay rate and half-life;
- atoms are made up of a central nucleus with a positive electric charge, orbited by negatively charged electrons.



Images of Marie Curie and Ernest Rutherford via the United States of America Library of Congress



Radium poisoning by ingestion was discovered in 1924 by New York dentist Theodore Blum. He found that women who worked as radium luminous clock dial painters (they used to lick their paint brushes to get a fine pointed tip), were getting diseased jaws. Ultimately, some one hundred women died of bone cancer of the jaw or nasal sinus bones, out of a total dial painter workforce of about two thousand. The story of the Radium Girls is a horrible tale of company neglect and cover-up. This prompted a series of studies by Robley Evans in the US Public Health Service, who worked out how to calculate internal radiation doses, and created the first workplace airborne radioactivity safety standards.

The need to control ingestion and inhalation of radioactive materials was thus recognised by the early 1930's.

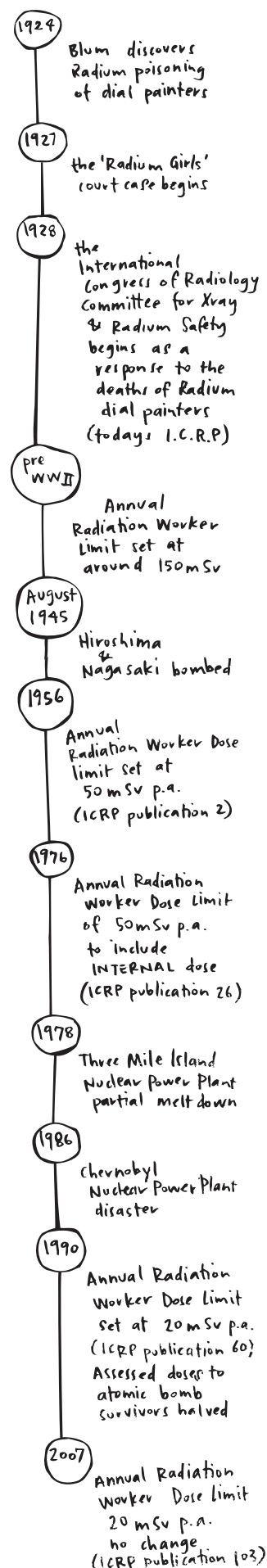
During the 1920's it was found that underground radium miners in Bohemia were suffering high lung cancer rates. This was not properly followed up, and in the 1950's and 60's a similar increase in lung cancers began to be reported in the uranium miners working in the US. Finally it became clear that it was the radon decay products (radon daughters or radon progeny) in the mine air that were responsible. These build up to extremely high levels in poorly ventilated workings, and are trapped in the lung's bronchial tree where they rapidly decay giving a large and immediate radiation dose to the bronchial cells.

The cumulative doses from RnD for underground U miners in the 1950s and 1960s were in order of 10 Sieverts (!!) based on characteristic working life RnD exposures of 2000 Cumulative Working Level Months (CWLM) and a conversion factor of 4 WLM = 20 mSv.

During the early 1970's various studies in the US and Canada determined the safe level of radon progeny in mine air (0.7 microjoules per cubic metre) and several reviews by ICRP since have confirmed this.

In 1928, the International Congress of Radiology set up the Committee for X-ray and Radium Safety. Now known as the International Commission for Radiological Protection (ICRP), it produces advice and recommendations for Health Authorities worldwide, on control of radiation doses to workers, members of the public, and medical patients.

The ICRP, formed in 1928, is the prime international body that recommends radiation safety standards.



3 History of Australian Uranium Mining

The first radium mine in Australia was Radium Hill in South Australia, discovered in 1910. Uranium ore was shipped to a radium refinery at Hunters Hill in Sydney, which operated from 1912-1916, and made about a gram of radium for use in cancer therapy and for luminous paint.

Small radium mines in the North Flinders Ranges near Arkaroola (Mt Painter, Mt Gee, Radium Ridge) operated from 1922-1933, producing 0.2 grams.



Radium Hill in the 1990s

Radium Hill was re-opened in 1951 by the SA Dept of Mines, for US/UK defence uranium production, and ran until 1960; it produced 850 tonnes of U_3O_8 in total, at a uranium ore treatment plant in Port Pirie South Australia.

Rum Jungle in the Northern Territory, discovered in 1949, operated from 1954-1970 and produced about 3700 tonnes of U_3O_8 in total.

Several small mines in the South Alligator River valley ran between 1954-1965, and produced a of total about 500 tonnes of U_3O_8 .

After closure, Rum Jungle was found to have caused major environmental damage in the East Finniss River, due to unregulated releases of acid tailings and liquor, followed by acid mine drainage from oxidizing copper sulphide in waste stockpiles. This discovery was a great embarrassment to the Australian Atomic Energy Commission which had been responsible for the mine, and CRA (Conzinc Rio Tinto Australia), which had the contract to run it.

Rum Jungle was later rehabilitated in the mid 1980's, by the Commonwealth, at a cost of about \$18 million.

Mary Kathleen Uranium in Queensland, operated from 1958-63, and produced 4000 tonnes of U_3O_8 . MKU was reopened from 1976-83 and produced around 4500 tonnes of U_3O_8 . It was rehabilitated by CRA in the mid 1980's.

New discoveries in the Uranium boom of the 1960s and 70s included:

NT	Ranger, Koongarra, Jabiluka, Nabarlek, Bigryli, Angela
Qld	Valhalla, Westmoreland, Lagoon Creek, Ben Lomond, Maureen
SA	Olympic Dam, Beverley, Honeymoon, Crockers Well
WA	Yeelirrie, Kintyre, Maitland, Mulga Rock, Thatchers Soak

The concerns raised by the management errors and lack of regulatory control at Rum Jungle impacted on the proposed Ranger Uranium Mine, and led to the setting up in 1975 of the Ranger Uranium Environmental Inquiry (the Fox Inquiry).

Amongst other things, the Fox Inquiry recommended the creation of Kakadu National Park, and the Office of the Supervising Scientist, which was to oversee future uranium mining projects in that area, which at that time were planned to be Nabarlek, Ranger, Koongarra, and Jabiluka.

By 1980, there were 3 active uranium mines: Mary Kathleen in Qld, and Ranger and Nabarlek in NT.

Ranger Uranium Mine has operated under a very high level of regulatory scrutiny for 30 years, next to World Heritage listed Kakadu National Park. Auditing by the Office of the Supervising Scientist indicates the mine has had negligible ecological impact on the surrounding Kakadu National Park.

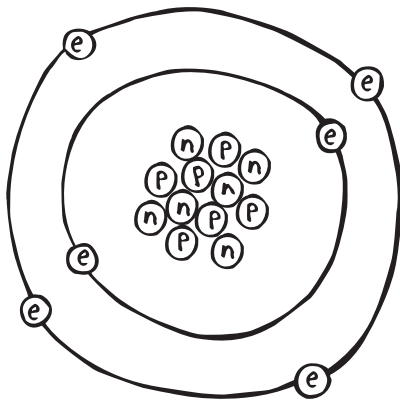
Before the start of underground development at Olympic Dam in SA, in 1982, there were concerns about the controllability of radon progeny in the mine air. However, quarterly reports by the company, and close overview by the Radiation and Mining Inspectors, show this hazard has been well controlled to date.

The In Situ Leach (ISL) operations at Beverley were regarded by some with concern as this was the first ISL mine in Australia. There were fears of contamination reaching the Great Artesian Basin (even though this is 100 km away and at higher hydraulic pressure). Close monitoring of the groundwater is required as a licence condition so as to detect any movement of mining solution from the immediate mining area.

‘New era’ uranium mining has been underway in Australia since 1976, at Mary Kathleen, then Nabarlek 1979, Ranger 1980, Olympic Dam 1982 and Beverley since 2001.

Present day Australian uranium mines operate under close government supervision and do not present workers or the environment with uncontrolled risks.

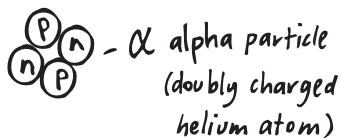
Carbon C_6^{12}



(e) - electron

(P) - proton

(n) - neutron



(e) - β beta particle
(high speed electron)

~~~~~ -  $\gamma$  gamma ray  
(wave of energy)

#### 4 Radiation Basics:

#### Atoms; Alpha, Beta & Gamma rays; Activity & Dose Units

Atoms are the smallest particles of matter that retain the properties of a chemical element (eg are recognisable as silver, carbon, oxygen, etc).

Atoms consist of negative electrons orbiting around a central massive positively charged nucleus, which contains protons (electrically positive particles) and neutrons (neutral particles).

The number of protons determines what element the atom is.

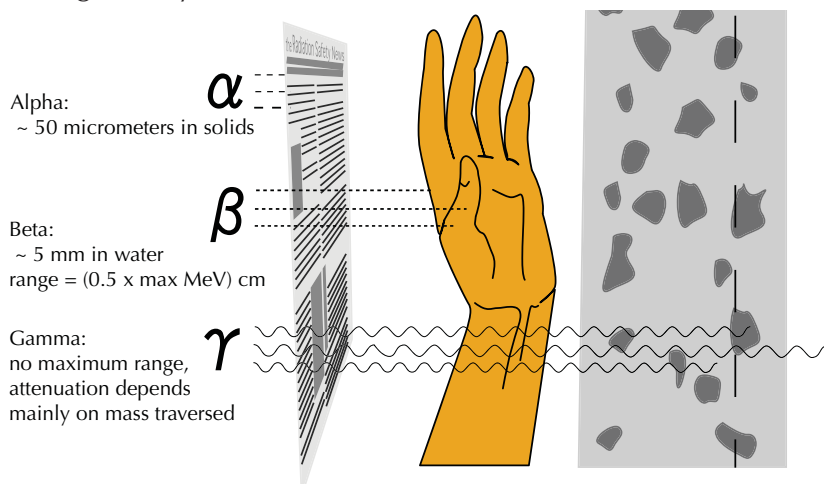
#### Types of Radiation

Radioactive atoms, including atoms of uranium, radium, and thorium, carry excess *energy*, and are unstable. They break down, or *decay*, to make new daughter atoms (of a different element) and at the same time give up some of their excess energy as alpha, beta, and gamma rays. Alpha, beta and gamma radiations have different penetration ranges in air, and in solid matter, and therefore affect biological tissue differently.

**Alpha particles** are electrically charged helium atoms, ejected at very high speed (30,000 km/sec) from the atom at the instant of breakdown. They are slowed and stopped by about the thickness of a sheet of paper (say 50 microns, 0.05 mm), or by about 3 cm of air. Alpha particles cannot get through the dead outer layer of the skin, but they make a dense ionization trail along their stopping track, so they can produce damage to biological tissue, if emitted inside the body following ingestion or inhalation.

**Beta particles** are electrons formed by the conversion of a neutron into a proton, and are emitted by the atom at nearly the speed of light (300,000 km/sec). They can travel a few centimetres in solids, and a few metres in air before stopping, but carry less energy, and give it up in a much more spread out and less dense track than alpha particles (so the damage is very much less).

**Gamma rays** are electromagnetic energy, like x-rays, are very penetrating, and pass with some reduction in intensity, through many centimetres of solids.



## Activity Units

The **activity** of a radioactive source or sample is measured in **Becquerels (Bq)**. One Becquerel is one atom decaying per second, a tiny quantity of activity. The old unit was the **Curie (Ci)**, equal to the activity of one gram of radium, which is equal to 37 billion Bq, a very large amount of activity.

## Dose Units

When radiation is absorbed by matter it deposits energy, causing ionization of the atoms. The **absorbed dose** is equal to the energy delivered per unit mass. The unit for absorbed dose is the **Gray (Gy)**, equal to one Joule of radiation energy deposited per kilogram of matter.

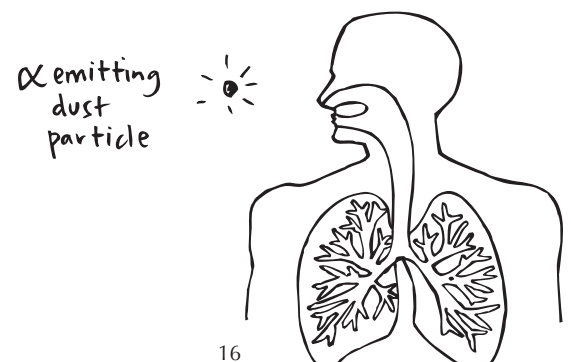
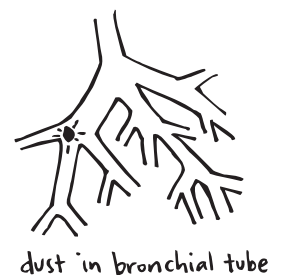
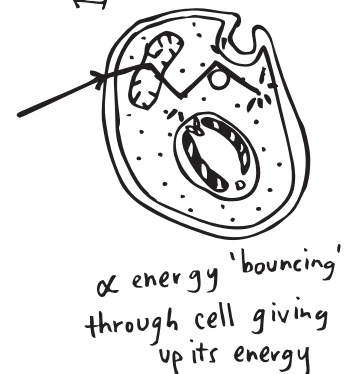
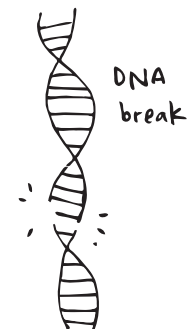
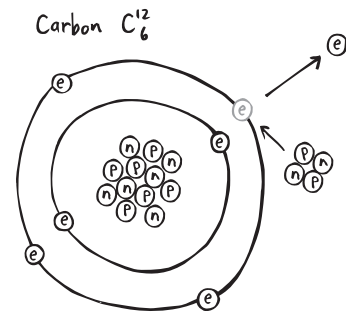
The amount of harm or risk to people caused by radiation depends not only on the total energy deposited (the absorbed dose) but also on the type of radiation and on the radiosensitivity of the organs being irradiated. This unit is called **effective dose**, and takes these factors into account, is used to quantify the harm or risk to people; and its unit is the **Sievert (Sv)**.

A Sievert is a very large dose, and so normally we talk about annual doses in units of **milliSieverts (mSv)**, which equal one-thousandth of a Sievert, and daily doses in **microSieverts (μSv)**, which equal one millionth of a Sievert.

## 5 Health Effects of Radiation

Health effects can be split into **acute** or **deterministic**, being effects caused by large doses in a short period of time, (such as skin burns, above 20 Grays, or vomiting, above 2 Sieverts); and **chronic**, or **stochastic**, leading to an increased risk of cancer from low doses over an extended period of time

There is also the hypothetical risk of **genetic** damage.  
UNSCEAR 2001 Annex: Hereditary Effects of Radiation, Section 542, p 83  
'no statistically significant adverse genetic effects ... could be demonstrated in the children of survivors of the Atomic bomb in Japan'





Gamma survey of natural background radiation  
Radium Hill

## 6 Natural Background Radiation and comparisons with Medical Doses

Uranium and thorium are widely present in the Earth's crust, averaging about 3 parts per million (ppm) of uranium and 10 ppm of thorium in ordinary soil, and up to 30 ppm or more of each in some granites. Uranium ores range from under 0.03% (300 ppm) up to a few percent (> 10,000 ppm) in the richest ores.

Radiation is part of our natural environment.

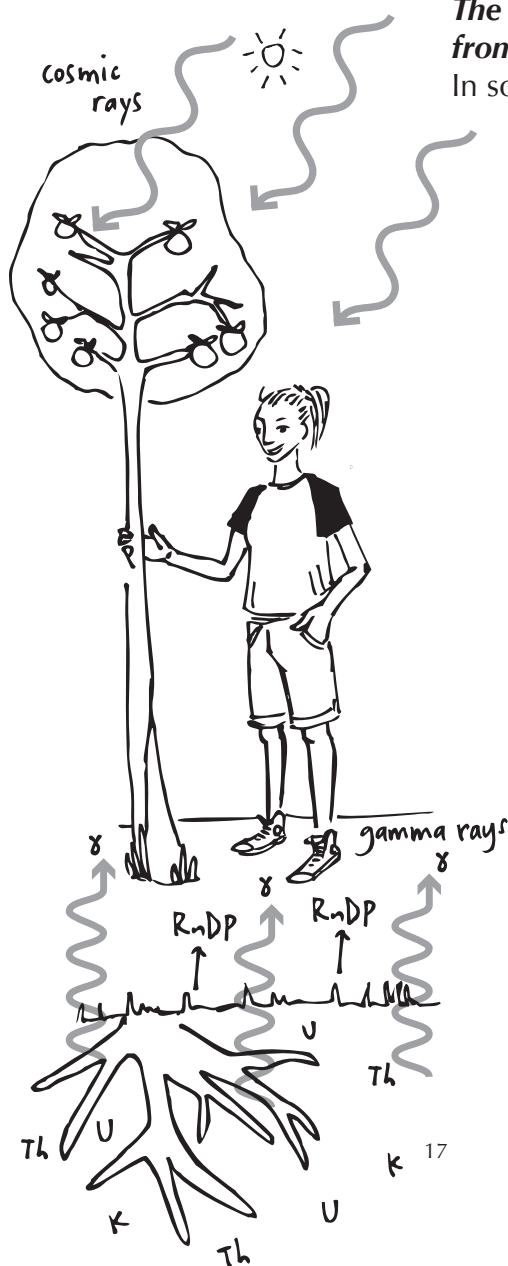
This **natural background radiation** comes from,

- gamma radiation from uranium, thorium, and potassium in the ground,
  - radon gas in the air,
  - cosmic rays from outer space, and
  - radioactive elements in our food and water,
- all giving us a radiation dose no matter where we live.

***Everyone is exposed to natural background radiation.***

***The world-wide population average annual dose from natural background radiation is about 2 or 3 mSv per year.***

In some places, annual background is well in excess of 10 mSv.



## Dose Comparisons

### Natural Background, Medical and Work Doses



- 2 mSv world wide annual  
average natural background  
radiation dose



Average annual radiation worker dose  
in Australia (2 - 5 mSv)



Technetium 99m heart stress test  
radiation dose (12 mSv)



Annual dose limit  
for radiation workers  
AND  
the dose from  
a typical CAT scan  
(20 mSv)



x 5000 = a deadly radiation dose (10 Sv)

At the low end of the scale, an arm or leg x-ray will give 0.02 to 0.05 mSv  
and a dental x-ray about 0.005 mSv.

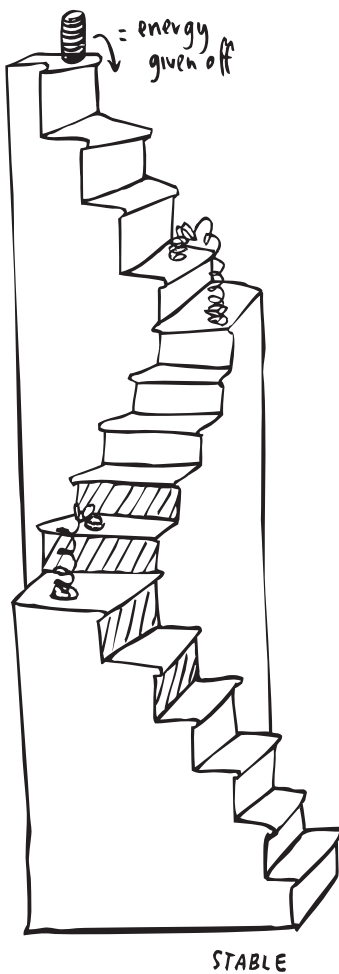
***The annual radiation dose you will get from working  
with radioactive ores, product and waste is similar to, but additional  
to, the dose you get every year from natural background radiation,  
and lower than the dose from a CAT or nuclear medicine scan.***

## 7 Sources of Radiation in the Resources Industries

Uranium and thorium are naturally radioactive metals and each is the parent of its own series of other naturally radioactive elements, shown below.

**The uranium and thorium decay chains list the different radioactive elements in the ore, and the types of radiation they give out.**

U Decay Chain



### U-238 Decay Chain

| Nuclide             | Radiation                | Half-life            |
|---------------------|--------------------------|----------------------|
| Uranium 238         | $\alpha$                 | 4.5 billion yrs      |
| Thorium 234         | $\beta, \gamma$          | 24 days              |
| Protactinium 234    | $\beta$                  | 1.2 minutes          |
| Uranium 234         | $\alpha$                 | 250 000 yrs          |
| Thorium 230         | $\alpha$                 | 80 000 yrs           |
| Radium 226          | $\alpha, \gamma$         | 1600 yrs             |
| Radon 222 (gas)     | $\alpha$                 | 3.8 days             |
| <b>Polonium 218</b> | $\alpha$                 | <b>3 minutes</b>     |
| <b>Lead 214</b>     | $\beta, \gamma$          | <b>27 minutes</b>    |
| <b>Bismuth 214</b>  | $\beta, \gamma$ (strong) | <b>20 minutes</b>    |
| <b>Polonium 214</b> | $\alpha$                 | <b>160 microsecs</b> |
| Lead 210            | $\beta, \gamma$          | 22 yrs               |
| Bismuth 210         | $\beta$                  | 5 days               |
| Polonium 210        | $\alpha$                 | 140 days             |
| Lead 206            | --- stable               |                      |

$\alpha$  = alpha particle, doubly charged helium nucleus,  
2 protons + 2 neutrons.

$\beta$  = beta particle, high speed electron emitted from nucleus.

$\gamma$  = gamma ray, electromagnetic radiation, similar to x-ray.

The radionuclides shown in **bold** are the radon progeny (radon daughters / RnDP).

Uranium workers should consider the effects of the decay chain for several reasons:

- (i) All elements in the chain are present in uranium ore
- (ii) Uranium has a very long half-life and is thus only weakly radioactive.
- (iii) Radium decays to radon which is a gas and can escape from uranium-bearing ore into the air.
- (iv) Radon daughters have short half-lives and thus after inhalation they decay rapidly in the lungs before clearance or elimination.
- (v) All of the long lived alpha emitters are present in ore and if inhaled, will deliver a dose to the human body
- (vi) Polonium-210 and lead-210 are volatilized in smelters and sinter plants and can build up in off-gas dust and fume collection systems.

- (vii) Both radium and uranium can dissolve in groundwater and migrate then re-deposit, or form radioactive scales as found in the oil industry.
- (viii) In exploration, the main gamma ray detected is from bismuth-214.
- (ix) The major part of the activity in uranium ore is not the uranium, but the other elements, which go to the tailings.

### Th-232 Decay Chain

| Nuclide                   | Radiation                         | Half-life         |
|---------------------------|-----------------------------------|-------------------|
| Thorium 232               | $\alpha$                          | 14 billion yrs    |
| Radium 228                | $\beta$                           | 6.7 yrs           |
| Actinium 228              | $\beta$ , $\gamma$ (strong)       | 6.1 hrs           |
| Thorium 228               | $\alpha$                          | 1.9 yrs           |
| Radium 224                | $\alpha$                          | 3.6 days          |
| <b>Radon 220 (Thoron)</b> | $\alpha$                          | <b>55 seconds</b> |
| Polonium 216              | $\alpha$                          | 0.15 seconds      |
| Lead 212                  | $\beta$                           | 10.6 hrs          |
| Bismuth 212               | $\beta$ (64%); $\alpha$ (36%)     | 61 minutes        |
| Polonium 212              | (64%) $\alpha$                    | 300 nsecs         |
| Thallium 208              | (36%) $\beta$ , $\gamma$ (strong) | 3.1 minutes       |
| Lead 208                  | stable                            | infinite          |

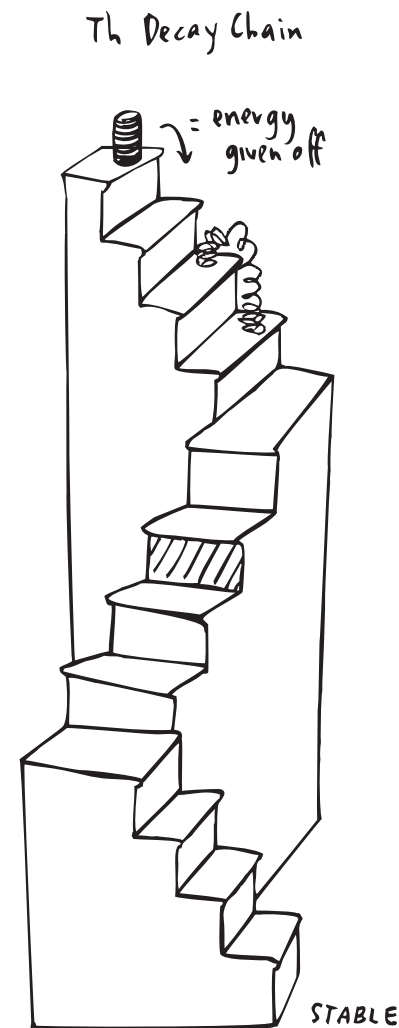
For workers, the issues which arise in this table are:

- (i) Thorium-232 has a long half-life and has very low activity.
- (ii) The main gamma emitters are actinium and thallium.
- (iii) Radon-220 is a gas like Rn-222, but its shorter half-life means it has less chance of escaping from thorium bearing ore into the air.
- (iv) All alpha emitters (as in the case of the uranium decay chain) can potentially deliver a committed dose if inhaled.

### Half life

**Atoms of each radionuclide 'parent' break down into atoms of their 'daughter elements' at the parent's own characteristic rate called the 'half-life'.**

After one half-life, only 50% of the parent atoms remain, the rest having decayed;  
after two half-lives only 25% of the original material remains, and so on.



**When each element in a decay chain is being produced as fast as it is decaying, and all nuclides have equal activity, the chain is said to be in ‘secular equilibrium’.**

Generally ore that is unleached or primary ore is in secular equilibrium. This is not necessarily the case in saturated, porous deposits, such as roll fronts and playa deposits, where uranium and / or radium may be continually remobilizing and redepositing. This **disequilibrium** can be a big issue for geologists as it causes radiometric assays to be in error (sometimes very badly so).

Similarly, **ingrowth** can be of concern for metallurgists who may find unexpected ingrowth of some radionuclides at recycle, condensation, or precipitation sites within process plants. For example, material containing Lead-210 will, over 140 to 280 days generate an increasing amount of its grand-daughter, Polonium-210.

Awareness of radioactive decay and ingrowth effects can be very important when assessing dose delivery pathways.

## **8 Dose Limit Philosophy & History**



Gembaku Dome  
Hiroshima, Japan

Historically, excess cancers and leukaemias have been seen in people exposed to large doses of radiation such as groups of overexposed medical patients and pre-WW2 radiologists. The biggest data set is from studies by the Radiation Effects Research Foundation, [www.rerf.org.jp](http://www.rerf.org.jp), set up in 1946, which continues to follow the health of the survivors of Hiroshima and Nagasaki, their children, and now their grandchildren.

### **The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)**

reviews and summarizes all studies into radiation and its effects.

The **International Commission on Radiological Protection (ICRP)** uses these studies in developing its advice and recommendations to regulators on the control of radiation and setting of dose limits. for workers and for members of the public.

For radiation protection purposes, and to err on the side of caution, the ICRP uses an approach called the **Linear No Threshold Hypothesis (LNT)** to estimate a 'risk per unit dose'. This estimate relies on assuming that risk is directly proportional to dose. The LNT hypothesis is the *assumption that risk increases in direct proportion to dose, and that there is no level of dose below which there is zero risk* (This is where the statement 'all radiation is harmful' comes from).

There are different specific biological situations where we know that the risk is not straight line but curvilinear, and where we know there is indeed a threshold, but the LNT hypothesis is used as a general and presumably conservative approach *for the purpose of setting dose limits*.

(Regardless of the actual dose response curve, it is true that at the very low doses that you get in normal radiation work, the risks are also very low.)

Using the LNT approach, the ICRP has assessed that a cumulative dose of **1 Sievert** in a **lifetime** in a population of exposed workers may incur an excess risk of cancer induction of 4%, over the rest of their lives.

The ICRP has therefore recommended 1 Sievert as the lifetime limit for workers, and assuming the worst case scenario of *fulltime exposure at the limit for 50 years*, this equates to one-fiftieth of a Sievert, or 20 miliSieverts per year. Thus the **Annual Dose Limit for Radiation Workers is equal to 20 mSv per year**.

The effects of radiation are well known. Annual Worker limits have changed only slightly over the years: the limit has reduced from essentially 50 mSv per year in 1956 to 20 mSv per year now. What can and does change is what society considers to be an acceptable level of risk.

***Changes in Limit (since 1956) have been minor.***

**The Annual Limit for Members of the Public, from human practices such as mining or industry, is set at 1 mSv per year,**  
on top of natural background and medical radiation.

The lower figure for members of the public, compared with workers, reflects the need for lower dose limits for children and pregnant women, and the fact that non-workers may have ongoing health problems. In addition, workers are also briefed on radiation safety, actively monitored, and are voluntarily receiving the dose in a controlled situation.

The ICRP also provides a philosophy for dealing with radiation. This is that doses arising from human activity must be:

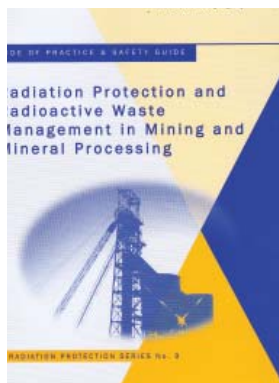
**Justified** - the activity must do more good than harm;

**Optimized** - the margin of good over harm must be maximised, that is, the dose must be As Low As Reasonably Achievable (ALARA);

**Limited** - dose limits must be used that give an adequate standard of protection even to the most highly exposed person.

**Thus we must keep doses 'As Low As Reasonably Achievable' social and economic factors being taken into account.** (The 'ALARA' principle)

This does **not** mean that we have to prevent every particle of radioactive mineral from escaping (which is impossible and unnecessary), or that we must shield against even trivial doses of gamma rays. It means that reasonable measures **must be taken** to minimize radiation doses.



**Australian legislation and dose limits come directly from the recommendations of the ICRP ([www.icrp.org](http://www.icrp.org)).**

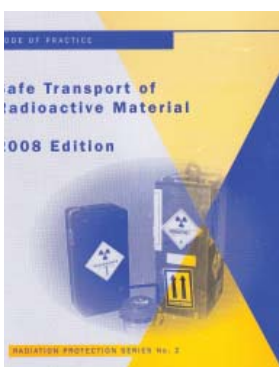
**Radiation workers on average, including miners of radioactive ores, receive between 2 to 5 mSv per year from work, compared with the limit of 20 mSv.**

## 9 Regulatory Regime in Australia

The **Australian Radiation Protection and Nuclear Safety Agency (ARPANSA)** develops Codes and Safety Guides.

The main guidance documents are *Radiation Protection Series #1*, the National Standard for Limiting Occupational Exposure to Ionizing Radiation; and for the mining industry, *Radiation Protection Series #9*, the Code of Practice for Radiation Protection and Radioactive Waste management in Mining and Mineral Processing.

ARPANSA Codes are adopted by States and Territories into their own regulations.



In South Australia, the Licence to Mine and Mill Radioactive Ores is granted on condition that the company must comply with the Code and with its approved Radiation Management Plan (RMP).

In the Northern Territory, the Department of Resources requires a Mining Management Plan, and NT Worksafe requires a Risk Management Plan, including a Radiation Management Plan, to be approved before any operations including exploration may start.

In Queensland, the Mining and Quarrying Safety & Health Regulation 2001 requires a Radiation Management Plan.

In Western Australia, the Mines, Safety & Inspection Regulations 1995 (part 16) sets out requirements for mining radioactive ores, including a Radiation Management Plan.

In each state additional Guidance Documentation has been developed.

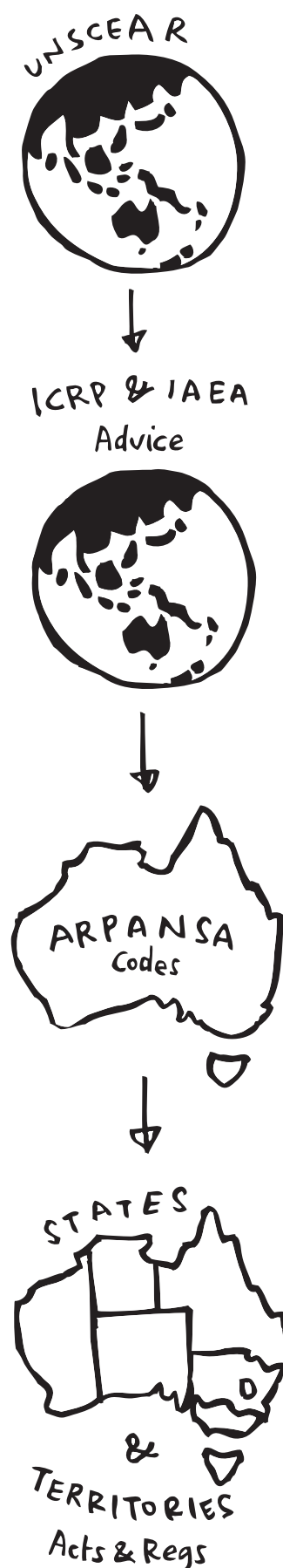
***The RMP is reviewed by the regulators against the requirements of the Code before grant of approval. There is then an annual audit of the company's compliance with its approved RMP.***

### Radiation Management Plans

ARPANSA's Mining and Processing Code, requires the operator, in their RMP, to provide a 'Description of Operations and Measures for Control of Radiation'; including

- Demonstrate access to professional expertise
- Plan for Monitoring exposure and Assessing Doses
- Provide appropriate equipment, staff, facilities, and procedures
- Induction and Training
- Record keeping and Reporting
- Plan for incidents/accidents/emergencies and
- Periodic Assessment and Review of Adequacy and Effectiveness of the RMP, to facilitate Continuous Improvement.

***Radiation Management Plans, once approved by the regulator then become licence conditions, i.e., they then become obligatory and must be complied with.***



## 10 Dose Control Methods for Different Situations

Assessments of the level of risk may differ markedly between different operations. The control measures adopted must be appropriate for the risk to be controlled. Different operations will approach the risk assessment task differently, but the process does need to be formal and documented.

In the design stage, HAZID, HAZOP, and other common hazard identification tools and Quantitative Risk Assessment measures drive design choices for hazard control. In operations, there should be pre-agreed investigation and intervention levels. At the workplace, hazard control is achieved by using Pre-start Job Safety Analysis tools (STOP, Take 5, PASS, etc).

Reverse Circulation drilling  
Nolans Bore



RC sample bags

### Exploration

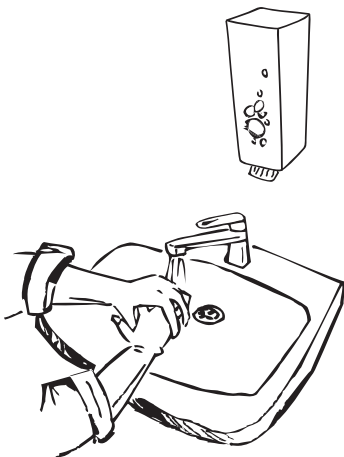
During exploration, the main need will always be to limit **inhalation of radioactive dust**, during soil sampling and splitting, and during RC drilling. These activities can all produce substantial levels of dust, and need controls to prevent it being breathed in or eaten or swallowed.

*If the work activities are unavoidably dusty, then you **must** wear a respirator or dust mask.*

**Gamma doses** will only require active control if you are working continuously on a large outcrop of radioactive mineralization or close to a large amount of high grade ore.

Before lunch and smoko breaks, you must wash your hands and face, to remove dust. This is to prevent the transfer of dust onto food or onto cigarettes and then to your mouth. Do not smoke in work areas; if you smoke, do so away from work areas and only after washing hands and face.

You should also shower and change clothes at the end of shift to avoid transporting radioactive dust into public areas, meal rooms or living areas.



## Mining

Different mine types have different radiation control priorities. In all cases, minimizing the spread of dust containing radioactive material, and monitoring for gamma hotspots are basic control methods.

For open cut mines the main dose delivery pathways are

- gamma irradiation
- inhalation of radionuclides in dust

Dust control is provided by wetting down of haul roads and blasted piles; water sprays at dump pockets; dust extraction at conveyor tipping points, crushers, and screens. Air conditioned cabins in plant equipment.

High grade mines (eg  $\geq 5\%$   $U_3O_8$  ore) may need shielding or particular design layout in some areas to minimise gamma doses.

In underground mines we need to control all three dose delivery pathways:

- gamma doses
- dust inhalation
- radon decay products (RnDP)

The RnDPs need to be closely monitored to track the effectiveness of mine ventilation controls.

In high grade underground uranium mines, gamma control becomes a major operational and design issue, with the need to keep workers away from ore intersections or to provide shielding.

In Situ Leach mines' main dose delivery pathways are

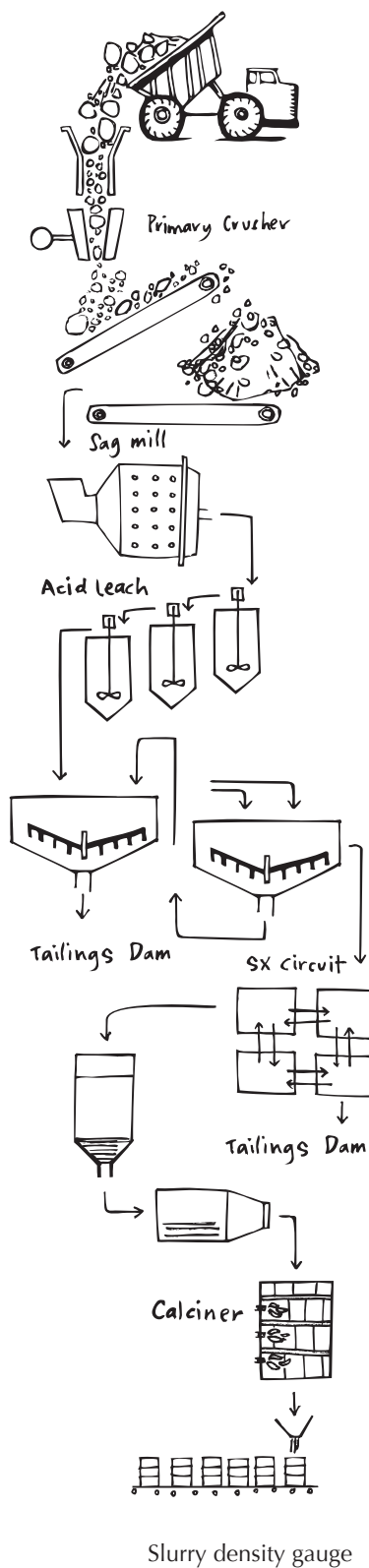
- gamma in pipes and tanks, and
- inhalation of radionuclides in dust in product packing.

There may also be a need to check radon build up in recirculated ground water.

Headframe Olympic Dam



Open pit Ranger



## Milling & Processing

Uranium ore is reduced by crushing and grinding to a fine particle size (usually between 20 and 150 micrometres) to enable leaching of the uranium.

Ore slurry is then leached, often using sulphuric acid with an oxidizer such as pyrolusite (manganese dioxide); or sodium chlorate; or hydrogen peroxide. The dissolved uranium solution is then separated from the undissolved solids in a liquid-solid separation stage using CCD (counter-current decantation) thickeners. Some plants overseas this is carried out using filterbelts.

The uranium solution (pregnant liquor) is then filtered through sand filters, purified and upgraded via either solvent extraction or ion exchange (SX or IX), ending up with a higher grade uranium solution from which the uranium product is precipitated and thickened, then dried or calcined, and finally packed, in 205 litre drums, for export.

Treatment plants are always designed to ensure all slurry and solution spills are contained, on a concrete floor that drains to sumps, where the spill can then be pumped back into the process. All spills must be washed so the floor is clean and the material is not allowed to dry.

## Gamma sources in treatment plants

There is a slow buildup of gamma emitters in sand filters upstream of the SX circuit. The other important gamma sources are the sealed sources (Cobalt-60 or Caesium-137) in bin level gauges and slurry density gauges. These gauges must be subject to formal control which allows work to be carried out near them safely. Isolations and removals may only be performed under supervision of the Radiation Safety Officer (RSO) or other licenced person.

***Sealed Source Gauges may only ever be moved under RSO supervision and are never to be disassembled!***

## Dust control in treatment plants

Dust control is an important issue in the crushing section of treatment plants, and especially in the product drying and packing area. Crushing circuits should always have dust collection hoods over all potential dust release points, e.g. conveyor tipping points, screens, crusher feed openings, etc. The extracted dust is then ducted to either wet cyclones or baghouses for collection and return to circuit.

Simple half face disposable dust masks are usually adequate but the site RSO will know when a higher grade P2 mask or half or fullface respirator or Airstream Helmet should be used, for example if very fine or particularly high activity dust is present.

Product drying and packing areas will **always** require use of respiratory protection such as Airstream Helmets or full-face mask. Maintenance work in product handling areas may require supplied air or powered respirators, and tasks should be subject to assessment by the RSO.

Surface contamination surveys (of offices and cribs) and instructions to maintain personal hygiene (by washing before eating) are the main ways by which the ingestion pathway is controlled.

### Mineral Sands Mines & Separation Plants

Mineral Sands mines and their processing or separation plants have very similar radiation control issues to those found in uranium mining. Monitoring of gamma radiation (using radiation badges and by workplace surveys) and of dust (by means of personal dust samplers) is virtually identical to the monitoring which takes place in uranium open pit mines and plants.

**Mineral Sands** mining operations may be an open pit, worked with bulldozers and scrapers, or a dredge pond, if ore is below the water table, in which ore is dredged from the advancing end of the pond and waste disposed at trailing end of the pond.

The raw ore from the pit or dredge pond is delivered to a Wet Plant, which uses Reichert Cones and Spirals to separate the heavy minerals from the silica and clay minerals. The Heavy Mineral Concentrate (HMC) is stacked and allowed to drain, then sent to a Dry Minerals Separation Plant ('Dry Plant' or MSP).

At the MSP the minerals are separated using, cross-belt magnets and electrostatic separators, to produce ilmenite, rutile, zircon, and possibly minor products such as xenotime and leucoxene. Dust in the MSP needs to be controlled, generally by enclosure. Up until the early 1980s, monazite (which contains thorium and is radioactive) was sold as a product, but at present it is usually disposed of with the MSP waste, into dredge pond, diluted with Wet Plant waste, or into the bottom of the open pit, where it is later buried. However, monazite is again being reviewed as a possible source of rare earths.

Radiation control in MSPs therefore involves gamma and dust control, particularly in the monazite waste separation area. Half-face respirators may be required in some areas for control of dust dose.

Reichert Spirals in Wet Plant  
Hamilton



Electrostatic Separators in MSP  
Hamilton

## Rare Earths Mines and Extraction Plants

Rare earths mines & process plants have similar radiation control issues to those found in uranium mines and mills, and mineral sand dry plants.

Extraction of rare earth elements requires strong chemical leaching (cracking) of the ore followed by separation by precipitation or solvent extraction of the rare earth products. The radioactive elements in rare earths (thorium and its daughters) are precipitated in a separation stage and the resulting radioactive waste filtercake is sent for disposal.

The radiation control tasks therefore focus on dust control at the front end of the plant, and then mainly on the safe and controlled handling of the waste filtercake to minimise gamma and dust. Personal protective equipment (PPE) may be required to limit dust dose, but should be regarded as the 'last line of defence'.

Cleaning NORM scale from coal washery vessels



## NORM (Naturally Occurring Radioactive Materials)

NORM occurs as radium scales in oil production, coal washeries, and fertilizer plants. Maintenance and refurbishment produces scale and sludge which is radioactive and this needs active management, and approval before disposal. Dust doses and gamma doses of maintenance workers may need to be monitored and controlled.

In copper and tin smelters, and in iron ore sinter plants, NORM occurs as a buildup of polonium 210 and lead 210 in off-gas dust and fume collection systems.

Monitoring and control is much the same as in uranium mines, ie, wet process for dust control, or use of PPE; and time-distance-shielding for gamma dose control.

*In all of the above plant situations, companies may choose to declare **Supervised Areas** where work may give doses higher than Member of Public Limits, and **Controlled Areas**, where active control and individual monitoring is needed to ensure worker doses are kept below Worker Annual Limit.*



NORM contaminated tubing from oil production wells

## 11 Environmental Controls

Before any mining activity can take place, regulators must be satisfied that any possible environmental impacts are avoided or minimized and are outweighed by the benefits of that activity.

*A major part of the review process is the Environmental Impact Statement (EIS) which has to be submitted for public comment and Ministerial review.*

There may be specific licence conditions imposed by the Federal or State Minister if the review of the EIS indicates a particular concern.

A principal responsibility for any mining company is to comply with its licence conditions, and prevent any unapproved release of radioactive material into the outside environment and to be able to show by monitoring a lack of impact on the environment.

Historically, environmental regulations were minimal, and there were impacts (South Alligator, Rum Jungle) that would not be acceptable today. *These impacts were due to chemical toxicity, not radioactivity.* These cases in fact provided the impetus for the stringent controls that we now have.

The level of environmental controls should depend on the type of activity being done, and on the sensitivity of the surrounding environment. A greenfields exploration camp doing soil samples and walk overs has much lower potential impact than a uranium metallurgical process plant with its tailings dams.

In exploration, we are required to collect and bury sample waste so that it cannot be spread by wind, rain or digging animals. *'What comes out of the ground, goes back into the ground'.* This waste should be buried according to a previously approved plan, in designated pits or costeans that are located by GPS, photographed and recorded. These records are vital to inform communities, regulators, landowners and land users *what* is buried *where*, and to demonstrate transparency.

In mining, milling and processing, the release of radioactive material from the site is tightly monitored and controlled through detailed procedures to ensure the environment and human health remain protected.

Radon production from tailings dams or waste rock stockpiles is controlled via capping the source material with clean fill or soil. This gives an average increase over natural background that is almost too small to measure more than a few kilometers away.

Checking a HiVol sampler  
Ranger



Routine water sampling  
Ranger

## Radioactive Waste Disposal

The classical approach to control of radioactive waste, is that you must either:

**concentrate & contain**, ie. collect and store; or  
**delay & decay**,  
ie. collect & wait while radioactivity decays away; or  
**dilute & disperse**, ie. release at low enough concentrations to sewer or watercourse under government approval.

For example, hospitals have 'delay' tanks to hold toilet waste from patients who have been given large activities of radioactive Iodine -131 for thyroid cancer (I-131 has a half-life of 8 days). Wastes from use of radiopharmaceuticals containing short lived isotopes such as Technetium-99m are flushed at a controlled rate into the sewer system (Tc-99m half-life is 6.7 hours).

Long-lived waste such as old radium sources must be stored indefinitely or buried. In Australia, Queensland has a Radioactive Waste Store near Esk, and Western Australia has an 'Intractable Waste Repository', near Kalgoorlie. These facilities provide WA and Qld with the capability for long term storage or permanent disposal of obsolete sealed sources and unsealed radioactive material in line with international best practice.

All Australian uranium mining and mineral sands operations are required to **contain** all radioactive wastes, in mined out pits or in engineered tailings dams. In the case of Olympic Dam, some tailings are used as underground mine stope backfill. Mineral sands operations are usually required to either bury the radioactive monazite tails in the base of worked out pits, or to dilute them with non-radioactive tails and place in the pits, or in dredge ponds, during backfilling.

Monazite wastes from mineral sands are insoluble, and cannot get into the watertable. They are essentially harmless unless inhaled or stored in such a high concentration as to make a gamma hot spot.

Some overseas uranium mines *cannot* evaporate tailings liquids, as their climate is too cold or too wet, and so have approvals to treat and release to local rivers.

## Baseline, Operational, and Post-Closure Environmental Monitoring

Environmental controls at mines & process plants must be planned and designed to fit each project's own circumstances (hot and arid, wet tropics, arctic, temperate,)

All licenses to operate a mine will require the company to rehabilitate the mine lease. It is important to obtain at the very start of operations a clear picture of what the pre existing state of the local environment was before disturbance. This baseline radiation monitoring, to define 'what was there before we started', generally includes gamma and passive radon surveys, soil sampling and possibly ambient dust monitoring, depending on the specific situation.

Regular operational monitoring is needed to check the effectiveness of environmental controls and also to give early warning of any build up of radioactive contamination on site that may cause rehabilitation problems later, if not fixed.

Post closure monitoring of mine and processing sites is important to assess the effectiveness of post closure cleanup and to assure regulators, communities, land owners and land users that there are no legacy wastes needing remedial action.

Passive dust sampler  
Angela



Baseline environmental studies  
Honeymoon



Product packed  
and labelled for transport  
Beverley and Ranger

Vehicle washdown  
Olympic Dam  
Surface contamination check  
Ranger



## 12 Transport

Transport of radioactive materials has to comply with state and territorial regulations, which in turn follow the ARPANSA Code of Practice for Safe Transport of Radioactive Material, which is drawn directly from the IAEA International Regulations.

ARPANSA's Code sets out a number of controls that must be followed, including package design, transport signage covering; **package labels**, and **vehicle or container placards**, **Shipper's Certificate**, **driver briefing**, and **emergency response plan**. This sets out the actions to be taken following a traffic accident that causes spillage of the material.

Generally, radioactive materials are packaged with at least two levels of containment, e.g., sample bags in box, yellowcake drums in seafreight container.

The packaging, labelling, documentation and planning depend on the radioactivity of the material and on the surface gamma dose rate of the package that is being transported. If these rules are followed, doses to workers who are transporting radioactive material will be well controlled.

Exploration samples can usually be classified as 'Excepted Packages', if not absolutely exempted from the Code of Practice for Safe Transport of Radioactive Material if the grade is lower than 800 ppm for uranium bearing samples.

Uranium ore concentrate ('yellowcake'), monazite product, and most bulk wastes, will generally be classified as Low Specific Activity material, LSA-1 or LSA-11.

## 13 Surface Contamination Controls & Clearances

Accidental dispersal of radioactive material can occur via dust or mud on anything leaving site.

***Nothing is allowed to go off site if it is contaminated with radioactive dust or mud!!***

This could be personal tools, heavy equipment, vehicles, drill rigs, or yourself. Radioactive contamination is *not magic*, it can be removed like any other dirt by washing. Anything leaving site control should be washed first, then checked and only after passing the contamination clearance, and formally recorded as clean, may it leave site.

***Everybody must follow the formal procedure for 'clearance' of potentially contaminated equipment before it is allowed to leave site.***

## 14 Radiation Monitoring Plans and Personal Dose Calculations

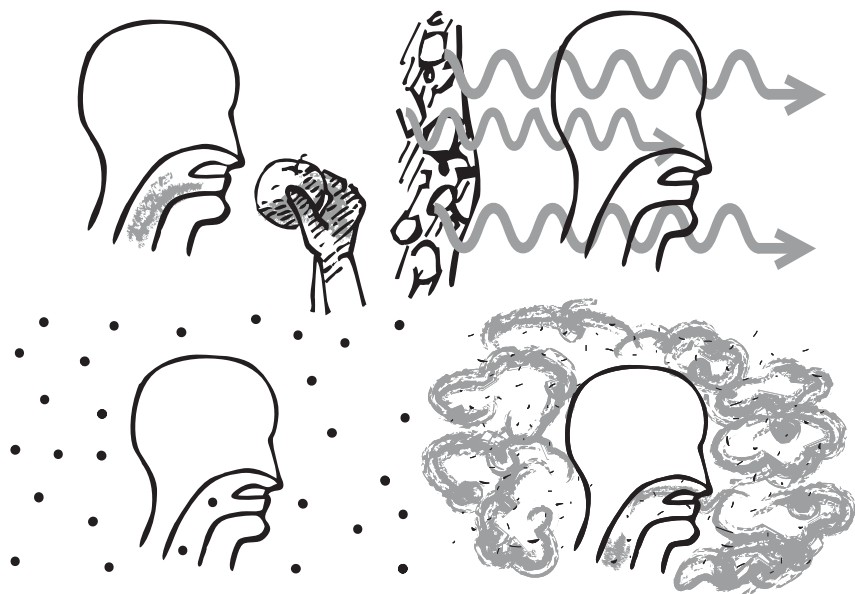
When working on sites handling uranium, thorium or radium bearing ores, product or waste, it is important to **monitor** radiation levels. There are several reasons for monitoring:

- provide day-to-day feedback and operational control to tell whether procedures are working and personal protective measures are needed - this calls for **rapid** reporting of high readings to foremen and senior management.
- licence conditions; regulators require workplace monitoring data be reported to them so that operations may be audited
- as input for personal dose assessments as needed under the Code of Practice.
- provide input for long-term control action plans such as changes in ventilation or dust control systems, etc
- for input to future epidemiological studies; note that it is essential to retain raw data, so that dose calculations can be reworked if conversion factors or internal dosimetry models, etc, are changed.
- to manage legal liability and prove duty of care.

*Monitoring allows us to prioritize the dose delivery pathways for the site or task and to check the effectiveness of radiation controls.*

The Monitoring Plan should include Personal Monitoring and Workplace (Area) Monitoring, and will track each dose delivery pathway.

A vital part of any monitoring program is to ensure that monitoring instruments are calibrated and working correctly.



| Type of Radiation                      | Personal Monitoring                                                                           | Area Monitoring                                                                                                    |
|----------------------------------------|-----------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|
| Gamma ('shine')                        | Radiation Badges;<br>Electronic dosimeters<br>for high dose rate jobs                         | Gamma survey meter                                                                                                 |
| Alpha long lived<br>(dust in air)      | Personal Air Sampler (PAS)<br>filters alpha-counted<br>after short delay<br>(1 day to 1 week) | Fixed PAS<br>or medium volume<br>or HiVol samplers                                                                 |
| Surface<br>contamination               | alpha 'friskers'<br>for individual checking                                                   | alpha probe surveys<br>of offices, workplaces<br>cuberooms,<br>changerooms, and<br>equipment for clearance         |
| Alpha short lived<br>(radon daughters) | Personal active<br>RnD monitors<br>or passive track etch<br>Rn monitors                       | gross alpha count<br>of short term<br>air sample filter activity;<br>Continuous monitoring<br>via hardwired system |

Personal radiation badge  
and gamma survey meter



Gamma survey  
Beverley

## Gamma irradiation

Personal radiation badges should be issued for any full-time radiation worker. These are to be worn at work (on shirtfront or on overalls; or on hardhat) and stored in a low-background area on a tagboard after you change out of your work clothes (or as instructed) when you are not at work. Don't lose your badge as you could be charged its replacement cost!

Badges are often issued for a 3 month wearing period, after which the Radiation Safety Officer (RSO) collects them, then sends them off for readout. Badge results are to be forwarded to each worker when they have been processed (around a month later).

In some cases an electronic dosimeter is used instead of a badge. These are worn in your shirt pocket and read out and recorded at the end of each shift or job activity.

Gamma survey meters (Geiger counters) are used to check workplaces for gamma dose rate (measured in microsieverts per hour).

## Radiation dose by Inhalation

### Long lived alpha emitters in ore, process, tailings, or product dust

Workers doing dusty work may be sometimes required to wear a Personal Air Sampler pump, to provide data on airborne dust levels. This samples air from your 'breathing zone' through a filter on which airborne dust is trapped. The filter is later counted by an alpha counter to assess the level of radioactive dust in the air.

This information enables the RSO to do dust dose calculations, and to assess the need (or otherwise) for use of respirators.

### Short lived alpha emitters (radon progeny)

This is a critical monitoring requirement of underground uranium mines. Check monitoring for radon progeny may also be carried out at open pit mines, for reassurance purposes. Air sampling pumps are put out and run for a specific time, and then the filter is counted immediately after to give the radon progeny concentration in workplace air.

The results are used by the mine ventilation engineer to assess the effectiveness of the ventilation system.

## Radiation dose by Ingestion

### controlled by surface contamination checks and personal cleanliness

There will usually be a surface contamination monitor ('frisker') available at crib rooms and washrooms so that you can check your hands before smoko and lunch, and after showering at end of shift. You need to wash your hands *before checking* to minimize the risk of contaminating the instrument!!

These instruments are also used to check for contamination on equipment which is to be released from site. Nothing which is to leave site for return to town or to a hirer may go until it has been cleaned and checked for surface contamination.



Short lived alpha count  
Nolans Bore

Surface contamination check  
in Well House  
Long lived alpha filter count  
Beverley



Instruments clockwise;  
Personal air sampler,  
long lived alpha filter counter  
surface contamination probe



## Personal Dose Calculations

Worker doses are calculated by adding the doses from each major pathway:

### **Total Dose**

**= Gamma Dose + Airborne Activity Dose + Radon Daughter Dose.**

**Gamma** personal dose is obtained from the radiation badge results

**Airborne Activity (Dust) dose** calculations rely on a sufficient number of personal dust sampler results to work out average levels for different workgroups. The average is then multiplied by the worker's hours spent on each task in each area. Daily timesheet cards are crucial: *you have to fill your timesheets out accurately!*

**Radon daughter dose** estimates are calculated (if needed) by recording each worker's total time in each underground workplace and multiplying those hours by the average concentration in that workplace. Daily timesheets giving hours / job / location data are needed for these calculations.

Personal radon daughter dosimeters bypass these problems but are expensive and require lots of technician care and attention. Passive radon monitors are cheap and simple but side - by - side radon and radon daughter readings need to be taken separately and repeated periodically to provide a calibration factor. In-mine fixed RnD monitors at multiple locations represent another approach.

**All workers' personal dose records have to be kept permanently, reported periodically, and must be made available to the worker on request.**

ARPANSA has been tasked to set up a National Dose register to record and maintain all worker doses information.

## 15 Your Role, Responsibilities, and Required Competencies

*The most important part of any safety program is you.*

You, as a worker in operations where you may be exposed to radiation, need to know how to work safely, and the basic methods of controlling and monitoring radiation in your workplace.

Both you and your employer have a responsibility to keep your radiation dose **As Low As Reasonably Achievable**. This means that your employer must provide a safe workplace, and you also must follow rules and use radiation controls correctly. If you see a defect, you have a legal obligation to bring these to your employer's attention.

You also have a legal duty to report any event which could be classed as a radiation incident or accident.

You will need to know how to:

- work safely and think about dose reduction
- assure 'duty of care' to your fellow worker
- Contain and promptly cleanup all spills
- Avoid spread of contamination
- Clean all equipment prior to it leaving site
- Use PPE and monitoring equipment as needed
- Wash before meals and at end of shift

You should note the name and contact details of the Radiation Safety Officer, and ask him or her any questions you may have.

Report any concerns to your supervisor

As part of your Induction Briefing or your initial training, you will be shown how to use personal monitoring devices, and Personal Protective Equipment:

**Use of TLD badge:**

Wear on clothing or hardhat as directed  
Store as directed (Tag board or change room)

**Personal Air Sampler:**

Filter holder in breathing zone  
Hose out of way to prevent tangles and kinks  
Report unusual dust situations  
Avoid blockages

**Self-check using**

**Surface contamination probe:**

for alpha emitters (surface contamination)  
on your skin and clothes, using a large-area surface contamination probe  
Pre-check wash, instrument check, ensuring enough count time  
Interpretation of readings

**Use of PPE:**

How to put on dust mask, and check seal  
Change filters and cleanse, if using half-face respirators  
or airstream helmets

*Understand the importance of, and how to use, Standard Operating Procedures (SOPs), Safe Work Permits (SWPs), and the local Danger Tag and Lockout rules.*

TLD badges on tag board



## 16 Comparison with Other Hazards

There are many hazards in the mining industry and much effort goes into controlling them. They can be categorised as **Acute** or suddenly injurious, like slips trips and falls, mechanical entanglement, thermal or chemical burns, impact, electrocution, vehicle accidents, sudden toxic exposure etc; and **Chronic** or injurious after prolonged exposure, like noise, silica, fumes, asbestos, nickel, and radiation.

The risk management and hazard control priorities will be different for every job, and most companies now use a Probability – Consequence matrix chart to decide on the urgency and priority of control of Acute hazards.

The Chronic hazards are those generally monitored by occupational hygienists (and Radiation Safety Officers) and are controlled by engineered shielding, time limitation, or PPE, so that time-in-concentration is minimized.

In all hazard control and risk minimization we should follow the 'Hazard Control Hierarchy', below:

Pre start meeting  
Olympic Dam



Seek first to **eliminate the hazard**; if this is not possible, then use **engineering design to enclose or isolate** the hazard, or somehow separate it in space or time from the workers by guards or interlocks; if this is not possible, then

**procedural controls** become necessary, such as Danger Tags and Work Permits.

Finally, hazards which are still present may need to be attenuated using **Personal Protective Equipment (PPE)**.

Radiation is a **minor** hazard in most circumstances and it is important for you the worker, and your supervisor, to ensure that all workplace hazards are looked after. Do not lose sight of the importance of controlling the acute injury hazards first and foremost.

*It is important that you don't increase other hazards as an unintended consequence of a radiation control action.*

The ALARA principle for limiting radiation dose should be used as a part of a total risk management strategy from a project's design phase through to regular on site job safety assessments and tool box meetings.

## 17 Conclusion

Over a generation's worth of studies, annual reports, and government audits showcase Australia's robust regulatory system and the scientific integrity of this system.

Australian uranium operations have been shown to keep doses to their workers and people living in nearby towns well below internationally accepted limits and do not impact the environment outside the disturbed area of the immediate mining and processing operations.

This experience has given Australia a leadership role in mining radiation safety. Keep up the good work.

### ***Final 'Do's and 'Don't's***

*Do - Follow instructions given  
in your Radiation Safety Manual and Induction*

*Do - Comply with Safe Work Permits  
and Standard Operating Procedures*

*Do - Care for monitoring equipment entrusted to you*

*Do - Wash hands and face before meals and coffee breaks*

*Do - Shower at end of shift*

*Do - Ensure any equipment leaving company control  
is first cleaned and checked for contamination*

*Do - Report anything that might be considered  
a 'radiation incident'*

*Do - Take an interest in your dose results  
and discuss control methods*

*Don't - eat or smoke except in clean, approved areas*

*Don't - lick rock samples*

*Don't - spread contamination offsite*

*Don't - take any samples as souvenirs  
unless formally checked & cleared*

*Do - check with your Supervisor or the RSO  
if there is anything you want more information on.*

### **Websites for further information**

Australian Radiation Protection and Nuclear Safety Agency  
[www.arpsa.gov.au](http://www.arpsa.gov.au)

Australian Nuclear Science and Technology Organisation  
[www.ansto.gov.au](http://www.ansto.gov.au)

International Commission on Radiological Protection  
[www.icrp.org](http://www.icrp.org)

United Nations Scientific Committee on the Effects of Atomic Radiation  
[www.unscear.org](http://www.unscear.org)

Radiation Effects Research Foundation  
[www.rerf.org.jp](http://www.rerf.org.jp)

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## Glossary

**Absorbed dose** – the amount of energy (in joules) deposited by radiation in a kg of matter;  
one Gray of absorbed dose = 1 J/kg.

**Activity** – amount of radioactive material in a sample, measured in Becquerels, where 1 Bq = 1 atomic decay per second.

**ALARA** – As Low As Reasonably Achievable, social and economic circumstances being taken into account.

**Alpha** – high energy, high speed particle radiation, actually a double-ionized helium nucleus, emitted from a decaying atom.

**ARPANSA** – Australian Radiation Protection and Nuclear Safety Agency

**Becquerel / Bq** – Unit of Activity see above; named after the discoverer of natural radioactivity.

**Beta** – energetic particle radiation, actually a high speed electron emitted from a decaying atom.

**Committed dose** – dose which you are ‘committed to’ following inhalation or ingestion of radionuclides; once incorporated into the body, these may continue giving a dose for many years.

**Contamination** – unwanted radioactive material, on surfaces or in air or water.

**Controlled Area** – area within which there must be specific procedures for ensuring control of worker doses below the limit; also, area within which the worker may get more than 3/10 of the Annual Worker limit.

**Decay chain** – sequence of transformations that a radioactive ‘parent’ atom passes through as it decays, giving out alpha, beta, and gamma radiation; see uranium and thorium decay chains.

**Dose** – may be absorbed dose, committed dose, equivalent dose, or effective dose.

**Effective dose** – dose to human body, taking into account the radiation weighting factor for effectiveness of different radiation types, and the organ / tissue weighting factor for differing radiosensitivities for cancer induction of the target organs.

**Epidemiology** – study of disease incidence in large groups of people.

**Exposure** – used in various contexts: may refer to the existence of an exposure pathway for delivery of internal or external dose; or sometimes may be inaccurately used meaning ‘dose’; may mean period of time in a radiation field.

**Frisker** - contamination probe for checking hands, clothes and equipment.

**Gamma radiation** – electromagnetic radiation like x-rays, emitted from the nucleus of an atom.

**Half-life** – time for a radionuclide to decay to half its original amount.

**Half Value Layer (HVL)** – the thickness of shielding which will reduce the strength of a penetrating gamma beam by half.

**HAZID** - hazard identification: structured process for identifying hazards and first pass review of potential controls.

**HAZOP** - hazard and operability analysis: structured process to check behaviour of plant in hypothetical upset conditions.

**IAEA** – International Atomic Energy Agency

**ICRP** – International Commission on Radiological Protection.

**Joule / J** – unit of energy (1 Joule =1 watt of power for 1 second).

**Kerma** – kinetic energy delivered from radiation into air: essentially same as absorbed dose in air.

**LNT** - Linear No Threshold hypothesis.

**LL  $\alpha$**  – Long lived alpha emitters (see decay chains).

**Member of Public** – not occupationally exposed to radiation.

**Monazite** – mineral, a rare earth-thorium phosphate, very resistant to leaching.

**NORM** – Naturally Occurring Radioactive Materials

**PAS** – Personal Air Sampler, for sampling airborne dust onto a filter paper.

**PPE** – personal protective equipment eg dust masks.

**PPM** - parts per million, a measure of the concentration of an element in ore.

**Quality Factor** – old terminology for Radiation Weighting Factor.

**Radiation** – transfer of energy through space.

**Radionuclide** – also radioisotope, a radioactive element .

**Radium** – discovered by Marie Curie, 88th element in the Periodic Table, the only source of intense radiation other than x-rays until the development of nuclear reactors and artificial radioisotopes in the 1940s and 1950s.

**Radon** – decay product of radium, an inert gas, similar to argon, neon, helium etc.

**Radon progeny / radon daughters / radon decay products / RnDP** - Po218, Pb214, Bi214, Po214, short lived radionuclide breakdown products of the decay of Radon-222.

**Secular Equilibrium** – the state in a decay chain when all nuclides are decaying at the same rate, i.e., all have the same activity, i.e., in each 'species', new atoms are being generated by breakdown of the parent just as fast as they are being removed by decaying to form their own daughters.

**Sievert / Sv** – Unit of effective dose.

**Supervised Area** – workers outside supervised area will not need to be regarded as occupationally exposed and will not get more than Member of Public limit; within supervised area, worker dose is unlikely to exceed 3/10 of the Annual Worker limit, and specific procedures to avoid going over the limit are not necessary.

**Tailings** - wet or dry waste product from processing.

**TLD Badge** – Thermo-luminescent Dosimeter, personal radiation badge, records time-integrated gamma dose.

**Thorium** – 90th element in the Periodic Table. A radioactive element found in small amounts in most rocks and soils, about as common as lead (~10ppm).

Th-232 decays very slowly (its half-life is comparable to the age of the Universe).

Thorium is commonly used in gas-lamp mantles, welding rods, and hi-tech alloys. Some nuclear reactor designs use thorium in their fuel cycle.

**Threshold** - a level below which there is no risk or effect.

**UNSCEAR** – United Nations Scientific Committee  
on the Effects of Atomic Radiation

**Uranium** – 92nd element in the Periodic Table. A radioactive element found in small amounts in most rocks and soils (~3ppm).

U-238 decays very slowly.

Uranium is most commonly used in nuclear power plants to generate energy and to create radioisotopes for use in research, industry and medicine.

**U<sub>3</sub>O<sub>8</sub>** - Uranium Oxide

**Working Level** – old unit for radon daughter concentration, equal to  $1.35 \times 10^7$  MeV of ultimately delivered alpha energy per litre of air, also equals (new units)  $20.7 \mu\text{J}/\text{m}^3$  ; originally defined as the alpha energy equivalent to 100 pCi/l of radon in equilibrium with its four shortlived daughters.

**X-rays** - discovered by Prof Wilhelm Roentgen in 1895.

**Yellowcake** - Ammonium Diuranate -  $(\text{NH}_4)_2\text{U}_2\text{O}_7$   
bright yellow uranium precipitate, but also colloquially used for uranium oxide U<sub>3</sub>O<sub>8</sub> which is in fact dark green!





The Australian Uranium Association (AUA) helped fund this handbook in order to provide workers in the uranium industry (and in other occupations involving radiation) with a general guide to safe work practices. The AUA did not contribute to the content of the guide, which is general in nature. The AUA advises readers of this handbook that they should not rely on it alone. Employees should be aware of and act in accordance with their employer's rules and practices regarding safe management of radiation at their workplace.



**Australian Government**

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While the Commonwealth Department of Resources, Energy and Tourism assisted financially in the production of this handbook the Department is not the publisher and has not contributed to the technical content. The content is unavoidably general in scope and does not necessarily contain advice by, or the views of, the Department as regards the safe handling of radioactive materials. In doing their work readers are encouraged to be aware of and act in accordance with their company's Radiation Management Plan.

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ECONOMIC PROSPERITY**

